Trans-Formers for Lunar Extreme Environments: Ensuring Long-Term Operation in Regions of Darkness and Low Temperatures

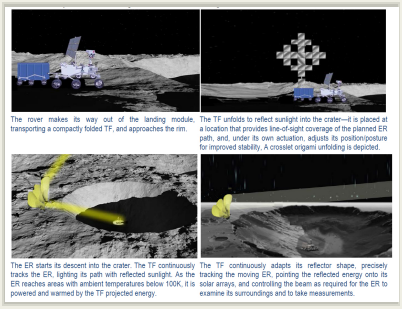
Completed Technology Project (2015 - 2017)

Project Introduction

Trans-Formers (TFs) transform a local area of a harsh extreme environment (EE) into a survivable micro-environment, projecting energy at the precise location where robots or humans operate. For example, placed on the rim of Shackleton Crater (SC) at a location that receives solar illumination for most of the year, TFs would reflect solar energy onto robots/base operating in the dark cold crater. - TFs use shape transformation to unfold from a compact volume to a large reflective surface, and to control how much - and where - the energy is projected, compensating for the changing position of the sun.

Anticipated Benefits

There are a number of immediate scientific benefits from the study, as contributions advance the state of the art in several areas. From a robotic perspective, it advances shape-changing, self-reconfigurable robots; origami-like TFs are at the same time robots, packages that unfold origami-stype and reflectors. It advances the use of multi-functional system integration in smart surfaces. It also opens new areas in solar energy, with technologies that would allow rapid deployment of solar energy production from compact volumes. Contributions to space technologies: These advancements are well aligned with multiple Technical Areas (TA) of the NASA Space Technology Roadmaps [28]: a) TA04, Robotics and Autonomous Systems, because in all respects, TFs are a new class of robots/autonomous systems, built in 2D, but reconfigurable to 3D shapes, with capabilities beyond the projections of the Roadmap; b) TA12, Materials, Structures, Mechanical Systems and Manufacturing, as it addresses innovative types of lightweight and multifunctional structures; and c) TA03, Space Power and Energy Storage, as it proposes innovative ways to redirect solar energy into shadowed exploration sites.



Arist depiction of Trans-Formers for Lunar Extreme Environments

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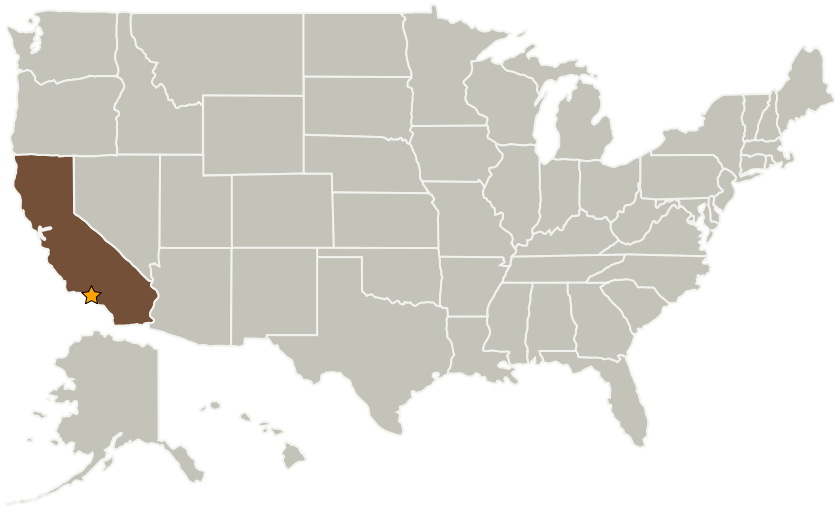
Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★Jet Propulsion Laboratory(JPL)	Lead Organization	NASA Center	Pasadena, California

Primary U.S. Work Locations
California

Project Transitions

July 2015: Project Start

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Jet Propulsion Laboratory (JPL)

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

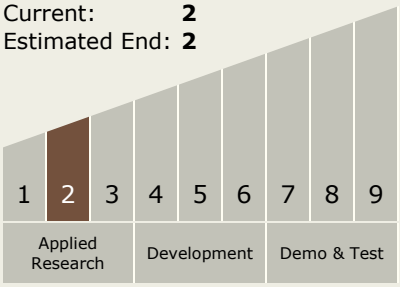
Eric A Eberly

Principal Investigators:

Masakazu Hirokawa
Adrian Stoica

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **2**



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June 2017: Closed out

Closeout Summary: The Moon is a highly valuable asset in humanity's move beyond Earth. Its polar regions harbor some of the most valuable real estate in the solar system. The regions are rich in solar energy, as their elevated altitude and polar location (the rotation axis of the Moon is almost perpendicular to the incoming sunrays) enables them to see the Sun for extended periods of time. Their permanently shaded regions (PSRs), such as the polar craters, are also rich in water resources. Yet, the Moon's natural environment is rather inhospitable for humans, as well as for equipment designed to operate on Earth, especially due to its freezing temperatures in areas that are not exposed to the Sun. The cold darkness restricts operations to 14 Earth days of exposure to sunlight (a lunar daytime), followed by 14 days of hibernation in the night, or to a few short hours, if robots venture into shaded areas like the polar craters powered only by batteries. Radioisotope thermal generators (RTGs) can ensure operation of certain classes of landers and rovers. However, each rover or asset deployed would need to carry one. They cannot satisfy the needs of power hungry equipment needed for mining and processing in-situ resources (MW). There is, however, an intriguing alternative to warm up and power the robots, and illuminate the darkness: one can project solar energy into the area of exploration, transforming the extreme environment (EE) of operation into a more hospitable one. The transformation of the local environment around the robotic or human explorers could be done by TransFormers (TFs). This constitutes a novel approach to addressing NASA's Space Technology Grand Challenge of Surviving Extreme Environments. The simplest TFs would be reflective surfaces placed in Sunilluminated places (e.g., on high ground, such as mountain peaks or rims of craters), which redirect sunlight onto the assets in the shaded areas, to power their solar panels, heat them, illuminate them and their surroundings, and relay communications. The more sunlight is visible to TFs, the more it is potentially available to the assets they irradiate in the darkness. As a wider area gets illuminated, the sunlight can heat and power more than one asset operating in the light 'spot' at no additional cost. TFs also make possible the operation of multiple smaller rovers/probes, which are challenged to accommodate their own power due to their compact size. As such, TFs could enable lower-cost missions, with increasing cost benefits for repeated missions in the same area, and for powering/warming multiple rovers/vehicles/habitats. TFs could redirect sunlight to locations kilometers away, e.g., from the rim of the lunar south pole's Shackleton Crater to its bottom, where it could ensure operations of both prospecting rovers and in situ resource utilization (ISRU) equipment. A 40-m diameter TF on the rim fully reflecting all incident solar radiation would provide an irradiation of ~300 W/m2 at 10 km into the crater. A solar-powered MSL-class rover with 6 m2 solar panels, operating inside the crater, would thus obtain the needed ~300 W electrical to move around and perform measurements, in what would otherwise be low 40-90 K temperatures. Ice water near the surface would take tens of minutes to sublimate under direct illumination of the soil, and longer for deeper ice deposits. Thus, short exposures, as may take place as 'side spill' during illumination of a rover as it traverses a region, should not impact the environment. On the other hand, in the absence of such concerns, concentrated heating from TFs could be used to sublimate water from the soil. In other words, rovers should not stop long over water deposits unless they are trying to extract the water; they should stop in rest areas or be prepared to protect the terrain otherwise, e.g., by using intermittent illumination, etc. An important challenge in our study of the TF concept was to determine survivability in the PSR, by providing uninterrupted power (day and night, every day of the year). This was shown to be possible to a large extent: the projection of solar power from a se

Technology Areas

Primary:

- TX07 Exploration Destination Systems
  - TX07.1 In-Situ Resource Utilization
    - TX07.1.2 Resource Acquisition, Isolation, and Preparation

Target Destination

Mars

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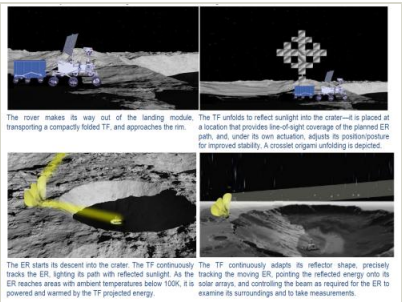
Images



Project Image
Arist depiction of Trans-Formers for Lunar Extreme Environments
(https://techport.nasa.gov/image/102058)

Links

NASA.gov Feature Article
(https://www.nasa.gov/feature/trans-formers-for-lunar-extreme-environments-ensuring-long-term-operations-in-regions-of-)

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html